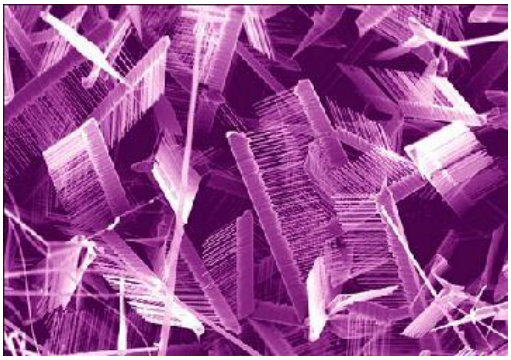
Nanoscale ESH for
R&D Operations

Introduction

This awareness training program is an orientation for research and development operations personnel and has a three-fold goal:

- **Raise awareness** of the environmental, safety and health (ESH) issues being identified in the rapidly changing science involving research and development of nanoscale particles.
- **Use the best information available to make interim recommendations** on environmental safety and health practices in the development and use of nanoscale materials. These recommendations will utilize a *hazard-based* approach to risk assessment.

Facilitate an exchange of information between researchers and ESH professionals to implement this hazard-based approach to risk assessment and control.



ZnO combs
Image provided by Zhengwei Pan

About this training

Individuals who work in facilities that engineer nanoscale particles should be aware of the known and potential associated health and safety hazards and the controls and strategies in place to reduce or eliminate these hazards. This training module will discuss:

- The Definition of Nanoscale Particles
- Toxicological Considerations
- Engineering and Control Procedures
- Personal Protective Equipment (PPE)
- Measurement Techniques
- Exposure Assessment
- Recommendations and Guidance

DOE Policy on Nanoscale Particles

The U.S. Department of Energy has issued a policy statement regarding nanoscale particles (DOE P456-1). See the entire statement here.

The DOE further delineates their policy through Notice N456-1, ***The Safe Handling of Unbound Engineered Nanoparticles.*** This notice can be found here.

DOE has established this policy to ensure the safety of all individuals working in and around R & D processes utilizing nanoscale materials.

The NSRCs are the DOE's flagship for the National Nanotechnology Initiative (NNI)

To support the synthesis, processing, fabrication and analysis at the nanoscale, the DOE Office of Science is developing, constructing and operating five new Nanoscale Science Research Centers (NSRCs). When complete, these five DOE Office of Science Nanoscale Science Research Centers will provide the Nation with resources unmatched anywhere else in the world:

The Center for Nanoscale Materials
Argonne National Laboratory
Argonne, Illinois

The Center for Functional Nanomaterials
Brookhaven National Laboratory
Upton, New York

The Molecular Foundry
Lawrence Berkeley National Laboratory
Berkeley, California

The Center for Nanophase Materials Sciences
Oak Ridge National Laboratory
Oak Ridge, Tennessee

The Center For Integrated Nanotechnologies
Sandia National Laboratories and
Los Alamos National Laboratory
Albuquerque, New Mexico

NSRC Facilities

The Centers are part of DOE's contribution to the National Nanotechnology Initiative, and they form an integrated network. These facilities are designed to be the Nation's premier user centers for interdisciplinary research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools and new computing capabilities.

Each Center will focus on a different area of nanoscale research, such as materials derived from or inspired by nature; hard and crystalline materials, including the structure of macromolecules; magnetic and soft materials, including polymers and ordered structures in fluids; and nanotechnology integration (BES).

About CNMS

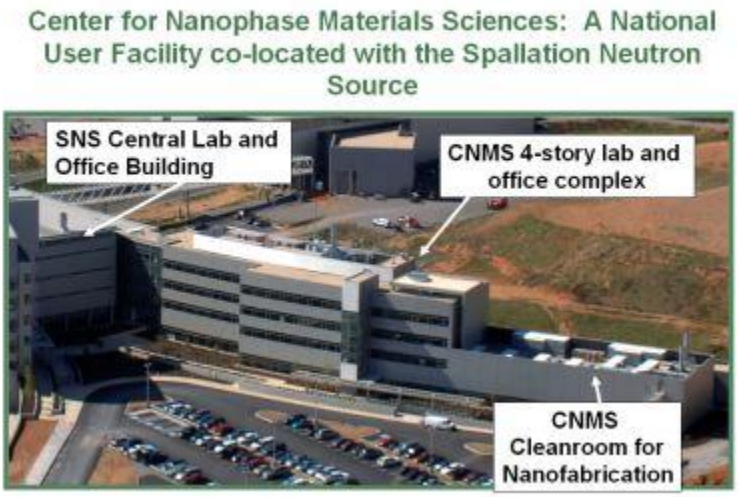
CNMS Integrates Nanoscale Science with Three Synergistic Research Needs

Neutron Science
Opportunity for world leadership using unique capabilities of neutron scattering

Synthesis Science
Science-driven synthesis: synthesis as enabler; evolution of synthesis via theory, modeling, and simulation

Theory / Modeling / Simulation
Stimulate U.S. leadership in using theory, modeling and simulation to design new nanomaterials - Investigate new pathways for materials synthesis

CNMS

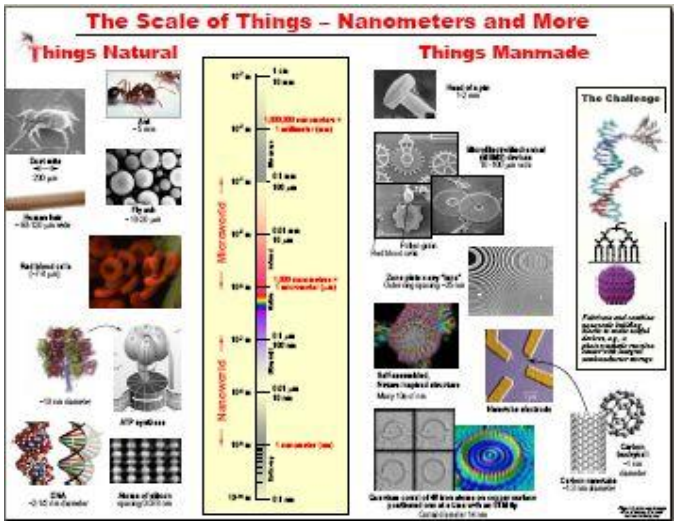


www.cnms.ornl.gov

What are Nanoscale Particles?

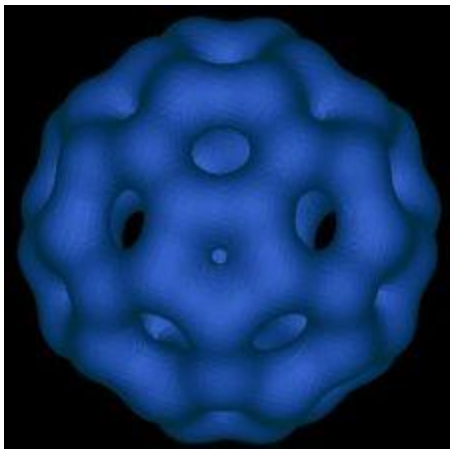
Nanoscale particles are near-atomic scale structures - typically between 1 and 100 nanometers (nm). [A nanometer is 1 billionth of a meter]. Nanoscale particles may be suspended in a gas (nanoaerosol), suspended in a liquid (as a colloid or nano-hydrosol), or embedded in a matrix (nanocomposite). Currently, there are dozens of consumer products utilizing nanoscale particles to impart remarkable qualities to common items. For instance, nanoscale titanium dioxide is widely used in cosmetics and sun-block; nanoscale silica is being used in dental amalgams; and nanowhiskers

are used to coat textile fibers to create stain and wrinkle-free clothing. The physical and chemical properties of nanoscale particles differ from the properties of individual atoms and molecules or larger scale materials of the same elements. Nanoscale research and development is focused on understanding and creating improved materials that utilize these new properties.



View the Office of Basic Energy Sciences "The Scale of Things"

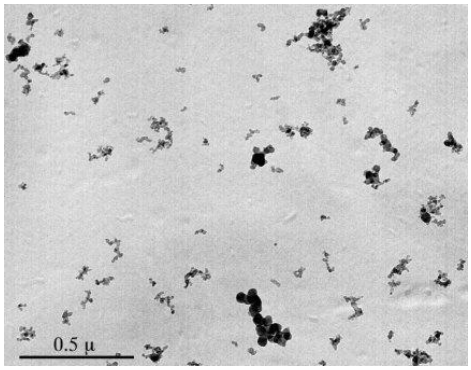
Types of Nanoscale Structures



Nanoscale particles (<0.1µm) are fabricated into a variety of structures and shapes from a variety of materials. Common engineered nanoscale structures are made of parent materials such as carbon, silicon, gold, silver, and titanium. Structures include: nanowires, nanohorns, nanoropes, nanotubes (both single-walled (SWNT) and multi-walled (MWNT)), and crystalline structures such as quantum dots and fullerenes (e.g., C_{60} "Buckyball")

"Buckyball" C-60 fullerene Source: UC Davis

Natural vs Engineered Nanoscale Particles



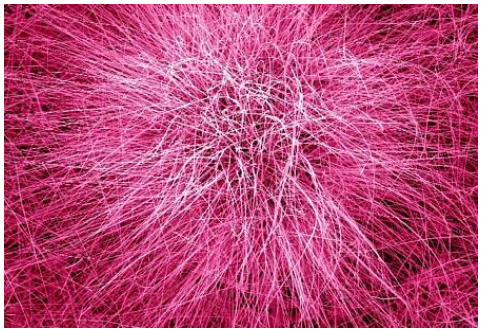
Nanoscale particles are not exclusively engineered. Most of our daily exposures to nanoscale particles come in the form of diesel exhaust; volcanic ash (which can travel thousands of miles in clouds); welding fumes; particulates given off when cooking; paint pigments; photocopier toner; cigarette smoke and other combustion products. Additionally, viruses and bacteria fall within the nanoscale (10nm to 10 µm in size). It is incorrect to assume that "natural"

nanoscale particles are safe - in fact, they are likely to be among some of the most toxic. Factors such as where we live have a great impact on our exposures to nanoscale particles. Individuals who live in urban environments may be exposed to millions of nanoscale particles every day - while rural exposures are thought to be many times lower.

Diesel nanoscale particles Source: NIOSH

Toxicity of Nanoscale Particles

The toxicology of nanoscale particles is an emerging science (as is the engineering of nanoscale materials). Nanotechnology research resources such as the National Institute for Occupational Safety and Health (NIOSH) the National Nanotechnology Initiative (NNI), Rice University's International Council on Nanotechnology (ICON) and the Nanoparticle Information Library (NIL), continually collect and assess studies on the toxicity of nanoscale particles. We do know that some types of nanoscale particles can be toxic - if they are not bound in a substrate and are available for uptake by the body. Many of the studies have conflicting and contradicting conclusions regarding the health hazards. Most experts recognize toxicological studies on ultra-fine particles as the best analogous health hazard data. Until further study is conducted on various nanoscale particles, information from these studies is considered the best available.



Source: Zhengwei Pan

Precautionary Principle or "Prudent Avoidance"

Until further information on the possible health risks and extent of occupational exposure to nanoscale materials becomes available, interim precautionary measures must be developed and implemented. Unlike historical R&D activities where it was assumed a material was safe until proven hazardous (i.e. asbestos, lead, PCBs, etc.), with nanoscale particles, we recognize the potential for human harm and we are constructing our procedures based upon the assumption that the materials could pose a significant health threat. This is known as the "precautionary principle" - assuming a threat and taking appropriate precautions. Since we cannot assign a "risk" to nanotechnology (a high amount of uncertainty exists), we will advance cautiously with the assumption that nanoscale particles can cause great harm.

Asbestos was used in hundreds of building materials with little thought to the potential toxicity to humans. Source: Glendale CC, AZ

Risk and Risk Perception

Without adequate information, all of us tend to miscalculate our risk to any given hazard. Most of us would never give a thought to a game of bowling. Many who bowl would never consider going scuba diving. In truth, bowling is a much riskier sport - many more injuries occur each year (per participant) than from diving. Human risks from nanoscale particles are not well known; therefore some of us will readily assume the worst. It is important for us to realize that until we have more and better hazard information on nanoscale particles, it makes little sense to jump to conclusions on the inherent toxicity. By utilizing a risk-hazard approach to managing engineered nanoscale R & D operations, we can safely and efficiently work with these new materials.

R &D Nanotechnology ESH Questions

Nanotechnology poses many unanswered questions about environmental and occupational health issues including:

- What are the target organs of concern?
- What is the toxic dose of nanoscale particles?
- What happens when nanoscale particles are released into the air, soil, or water?
- What happens when nanoscale particles enter our food supply?
- What kind of unique waste issues occur when we dispose of nanoscale particles?

Potential Fate of Nanoscale Particles in the Body

Once in the body, nanoscale particles will have one of the following fates:

- Expelled by natural protective mechanisms (coughing, sneezing, etc.)
- Re-ingested
- Benign (no negative health effects)
- Local tissue damage (i.e. irritation, swelling)
- Dissolution (particle is broken-down)
- Translocation (particle is moved to another part of the body)
- Systemic toxicity (dissolution and translocation)
- Interaction within cells (mitochondria, DNA etc…)

Source: alibaba.com

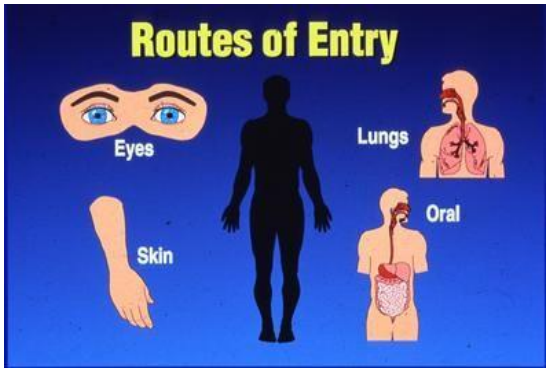
Potential Health Effects of Nanoscale Particles

Unfortunately, health effects cannot be readily extrapolated from common (larger) parent material. For instance, we can't use the known toxicology of carbon dust to judge the toxicity of single-walled carbon nanotubes. The most significant factors governing nanoscale particle toxicity are:

- Size
- Shape
- Solubility
- Chemical properties
- Charge
- Surface porosity
- Surface Area

To assure safety we currently assess health effects on a case by case basis for each individual material.

Nanoscale Particle Toxicity - Routes of Entry



For any toxin to cause harm, it must first get into the body. This "route of entry" is typically one of the most important factors in the type and extent of effect that a toxin may elicit. The three primary routes of entry that a nanoscale particle may follow are:

- Inhalation - respiratory tract
- Ingestion - gastrointestinal tract
- Dermal - through the skin

Let's further examine these routes of entry.

Routes of Entry – Dermal

Currently, no evidence concludes that nanoscale particles can enter the body via the

dermal route. Commercially available sunscreen lotions often contain nanoscale titanium dioxide and studies have indicated no acute or chronic harm from this material. However, due to the paucity of toxicological study in this area, we again assume that the intact skin is a plausible route of entry and subsequently take appropriate precautions against skin contact with engineered nanoscale particles. It is much more likely that these particles could enter broken skin or mucous membranes; therefore, we must take appropriate precautions to protect the skin, eyes and mucosa.

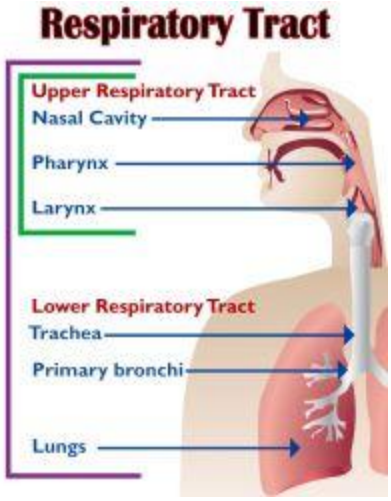
Routes of Entry - Ingestion

Ingestion is another route whereby nanoscale particles may enter the body. Ingestion can occur from unintentional hand to mouth intake of particles. Consumption of beverages and food, smoking or applying cosmetics is strictly prohibited in laboratories for this reason.

Ingestion may also accompany inhalation exposure because particles that are cleared from the respiratory tract via the mucociliary escalator may be swallowed.

Currently, no credible toxicological studies exist regarding health hazards from ingestion of nanoscale particles. Ultra Fine Particles (UFP) studies suggest that ingested nanoscale particles would likely accumulate in the liver; therefore we can assume that indiscriminant exposures through this route could lead to liver damage.

Routes of Entry - Inhalation



Of the three likely routes of entry, by far, the respiratory route is the most significant and requires the greatest amount of protection. We know that based on particle physics, nanoscale particles released into the air will remain airborne for considerable periods of time. Studies on ultra-fine particles (UFP) suggest that respired particles (particles deposited in deep lung tissue) may cause granulomas (microscopic nodules) and inflammation which can lead to tissue damage and reduced lung function. Because nanoscale particles readily agglomerate (primarily because of their polar nature) – this may significantly reduce the inhalation toxicology. Inhaled nanoscale particles may be inhaled and collected in all regions of the respiratory system.

ESH controls and protection plans strongly focus on this potential and we must try to limit to the extent feasible, our exposures to airborne nanoscale particles.

Source: Cal Poly Pomona

Working Safely With Nanoscale Particles

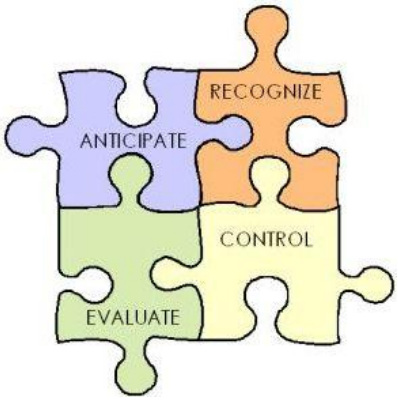
Working safely with nanoscale particles is dependent upon *laboratory work control*.
Hazards to nanoscale particles must be assessed before R & D procedures have begun. At CNMS, laboratory work control is incorporated in the Research Safety Summary (RSS). The RSS is a "researcher driven", cooperative effort between the investigator and

ESH. The RSS helps control and minimize all health hazards associated with research and development activities. All reasonable steps must be taken to prevent inhalation, dermal absorption, and ingestion of nanoscale particles and the RSS is the first step in this preventive approach.

Controlling Potential Exposures to Nanoscale Particles

ESH uses the primary tenets of industrial hygiene to control occupational exposures:

- Anticipate
- Recognize
- Evaluate
- Control



Control of occupational exposures is categorized in the following three ways:

- Engineering
- Administrative
- Personal Protective Equipment (PPE)

Personal Protective Equipment for Nanoscale Procedures

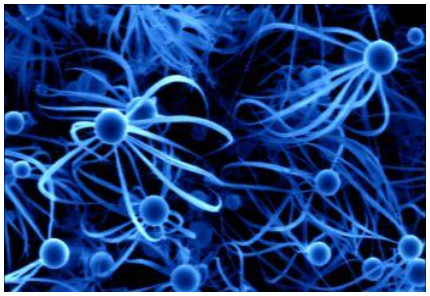
Personal Protective Equipment is the least reliable form of control; however, it is an excellent choice to combine with the other controls. Gloves, eye protection, and skin protection are excellent choices for reducing or preventing exposures. Respiratory protection is generally a "last resort" for protection from any airborne toxin due to the physical stress it can cause to the wearer. ESH and Medical professionals must approve any use of respiratory protection.

At a minimum, R & D personnel must use appropriate gloves (typically disposable nitrile gloves); eye protection (safety glasses, or goggles as appropriate); and skin protection. Work practices must consider prevention of para-occupational exposures, that is, wearing contaminated clothing home where family or others may come in contact with hazards that originated in the workplace. Where nanoscale particles cannot be otherwise controlled, facilities for showering and changing clothes should be provided to prevent the inadvertent contamination of other areas (including take-home) caused by the transfer of nanoscale particles on clothing and skin.

Administrative Controls for R & D Nanoscale Procedures

Administrative controls are less protective than engineering controls but can be very useful. Examples of administrative controls are limiting the amount of time individuals work with nanoscale particles and developing good workplace practices (SOP/SOGs)

to help minimize leakage, spills, and other potential exposures from particular R & D processes.



Ga ball-Si crystal-SiO_x nanowire octopus
Image provided by Zhengwei Pan

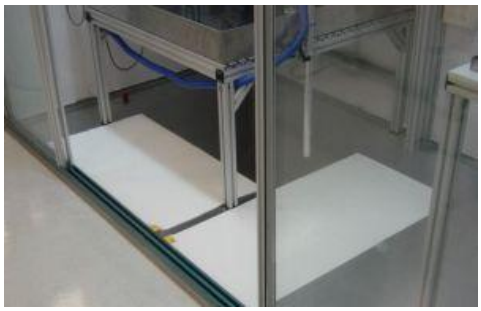
Engineering Controls for Nanoscale Procedures

Engineering controls are by far the best choice for protecting against occupational

hazards, including nanoscale particles. Engineering controls are best designed for each unique R & D process and are typically designed in concert with the researcher and ESH.

Engineering controls are the most valuable in that they remove the hazard from the work environment (typically through ventilation and filtration). Enclosed procedures, High Efficiency Particulate Air (HEPA) filtration, and encapsulated processes are all examples of engineering controls used in R & D nanoscale procedures to reduce exposures.

Good Work Practices for Nanoscale R & D Facilities



The incorporation of good work practices in an ESH hazard-risk program can help to minimize worker exposure to nanoscale materials. Examples of good practices include the following:

- Work areas should be cleaned at the end of each work shift (at a minimum) using either a HEPA-filtered vacuum cleaner or wet wiping methods. Dry sweeping or air hoses should not be used to clean work areas.
- Cleanup should be conducted in a manner that prevents worker contact with wastes.
- The disposal of all waste material should comply with all applicable Federal and State, and local regulations.
- Hand-washing facilities must be provided and workers encouraged using them before eating, smoking, or leaving the worksite.
- PPE must be worn and maintained as required in the R & D procedures - consult with ESH to choose the appropriate PPE for the operation.

ORNL - Procedures to minimize particulates - sticky mats and gowning procedures Source: NIOSH

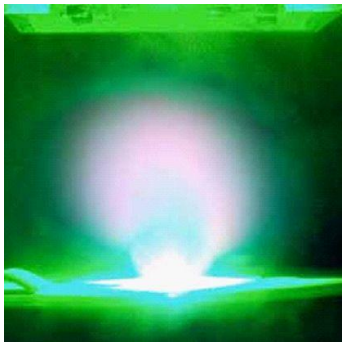
Cleanup and Disposal of Nanoscale Materials

Until relevant information is available, spills and contaminated surfaces should be treated as if a hazardous material were present. Standard approaches to cleaning up powder and liquid spills include the use of HEPA-filtered vacuum cleaners, wetting powders down, using dampened cloths to wipe up powders and applying absorbent materials/liquid traps. Damp cleaning methods with soaps or cleaning oils is preferred. Cleaning cloths should be placed in sealable containers (such as a zip-lock bag), labeled appropriately and disposed of according to ORNL guidelines. Drying and reuse of contaminated cloths can result in re-dispersion of particles. Use of commercially available wet or electrostatic microfiber cleaning cloths may also be effective in removing particles from surfaces with minimal dispersion into the air. Energetic cleaning methods such as dry sweeping or the use of compressed air should be avoided or only be used with precautions that assure that particles suspended by the cleaning action are trapped by HEPA filters. If vacuum cleaning is employed, care should be taken that HEPA filters are installed properly and bags and filters changed according to manufacturer's recommendations (NIOSH).

All HEPA vacuums must be approved by ESH prior to purchase. ESH will also provide guidance on use and maintenance of HEPA equipment.

HEPA Vacuum for cleaning nanoscale particles

R &D Nanotechnology Tools



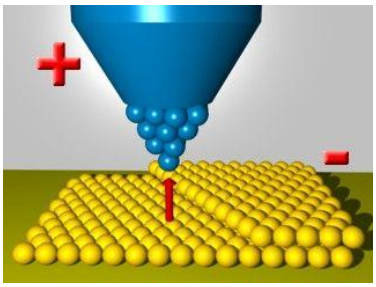
Typical R & D processes for creating nanoscale particles:

- High Pressure Co deposition
- CVD
- Plasma Torch
- Laser Ablation

Started with Carbon (Buckyballs, nanotubes, nanowires) now polymers and biological systems and beyond

ORNL - Laser ablation creation of single-walled nanotubes (SWNT)

R &D Nanotechnology Tools – Imaging



Typical R & D processes for imaging nanoscale particles:

- Raman Spectroscopy - Bond Energies
- IR & UV Spectroscopy
- Atomic Force Microscope (AFM-3D Image Surface)
- Scanning and Transmission Electron Microscopy (SEM, TEM)
- Scanning Tunneling Microscopy (STM-3D Image Surface)

- Magnetic Resonance Force Microscopy (MRFM)

Evaluating Potential Exposures to Nanoscale Particles

ESH is dedicated to characterizing potential exposures to health hazards in the occupational environment. Technology is emerging to help evaluate nanoscale particles in the environment and the use of this technology will further evolve as we continually learn more effective and efficient means to monitor. Currently, the following techniques are utilized:

- Mass – MOULDI Impactor, Photometers
- Surface Area – Diffusion Charger
- Count – CPC (TSI), Scanning Mobility
  Composition/Chemistry - GC-MS
- Surface Physics
- Transmission Electron Microscopy (TEM)

What is the correct/best index of exposure? This is determined in concert with the R & D researcher and ESH.

ORNL - Using the TSI 3007 Condensation Particle Counter (CPC) for nanoscale particle characterization

Nanoscale Particle Exposure Characterization in CNMS

CNMS ESH has developed the following protocol for characterizing nanoscale particles:

- TSI 3007 CPC, particle counts to 10nm
- Nucleopore Filter + SEM/TEM
  - size
  - shape
  - metallic composition
- Baseline Index of "clean" watch for other sources (air pollution, combustion)
- Direct count, estimated mass, and surface area for each process
- Surface contamination – "smears" + SEM

CNMS Researcher and ESH evaluating engineering control efficacy

Safety Hazards Associated with Nanoscale R & D Processes

Again, very little is known about the safety risks that engineered nanoscale materials might pose. The potential safety concerns most likely would involve catalytic effects or fire and explosion hazards. This assumes they will behave like materials of similar constructs. R & D processes have a wide variety of safety hazards ranging from lasers and UV, compressed gases and

cryogenic hazards to fire and explosions. ESH has prepared specific training modules to address these hazards.

Contact your supervisor or host or an ESH staff member to discuss the physical safety hazards associated with your R & D operations.

ORNL - Silane leak causing spontaneous combustion in air.

Waste and Bio-Magnification of Nanoscale Particles

Virtually all R & D facilities produce waste and some fraction of that waste is considered hazardous. Currently, we don't have adequate data to determine if nanoscale particles constitute hazardous waste. What we do know about nanoscale particles:

- Many nanoscale particles are not biodegradable.
- Very little is understood about the health effects of nanoscale particle exposures.
- If nanoscale particles are dispersed in the environment, there is a great likelihood that they could accumulate in the food chain.
- It is also likely that nanoscale particles could accumulate within some species.
- Until we have more and better information on toxicity, we should treat nanoscale particles as if they were hazardous.

Medical Surveillance

Currently, there are no specific medical tests that would determine if an individual had been harmed by nanoscale particles. In lieu of specific tests, the Department of Energy Notice 456.1 states that all employees who are engaged in nanotechnology activities be offered medical surveillance. DOE also states that guests/users be informed of the requirements of the Medical Surveillance portion of this notice but need not apply such requirements to guests/users. This requirement applies to designated "nanomaterial workers" as defined in DOE N456.1. This surveillance is described as follows:

The baseline medical evaluations must include:

- General physical exam;
- Pulmonary function test;
- General blood work; and
- Other tests or exams as determined by the DOE occupational medical provider.

Recommendations and Guidance

One of the goals of this training is to initiate a dialog between R & D personnel and ESH regarding safe practices for engineering nanoscale materials. ESH professionals can help assist with answering questions and can help design a specific set of work practices to make each particular work environment as safe as possible.

Additional guidance can be acquired from NIOSH. Their most recent guidance document - "Approaches to Safe Nanotechnology".

COMPLETION FORM

CNMS NANOSCALE ESH FOR R&D OPERATIONS

I acknowledge that I have read all of the information contained in this self-study.

Print Name:_____

Signature:_____

Date:_____